§16. Consideration of Mode-Content Analysis Using a Millimeter-Wave Beam Position and Profile Monitor

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In an ECRH system, it is important to precisely align a propagating millimeter-wave (mmw) beam to a transmission line to avoid mode conversion to the other higher-order modes. We have been developing a real-time beam-position and profile monitor (BPM) to measure the intensity profile of a high power (Megawatt level) mmw propagating even in an evacuated corrugated waveguide without any disturbances. It was improved to obtain higher spatial resolution [1]. The BPM consists of a reflector, two-dimensional Peltier-device array and a water-cooled heat sink which are installed in a miter-bend of the transmission line. Test results using a circular electric heater as a simulated heat source is shown in Fig. 1.

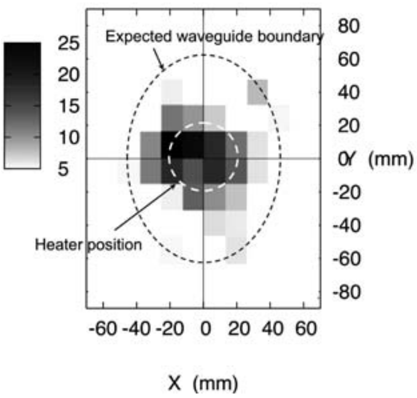

Fig. 1: Variation of each Peltier device voltage is mapped. The white dashed-line circle indicates the heater position attached and the black dashed-line shows a cross section of a waveguide.

Using the signals obtained by the BPM, a method of mode content analysis is considered according to the method proposed in the reference[2]. For simplicity, linear polarized modes in a circular corrugated waveguide are considered, which are expressed as the following equations;

$$\mathrm{LP}^{\mathrm{y}}_{\mathrm{nm}}(\mathrm{e}): \boldsymbol{E}_{\perp}(r,\theta) = \hat{y}\sqrt{2} f_\sigma J_n(X_\sigma \cdot r/a)\cos(n\theta) \quad (1)$$

$$\mathrm{LP}^{\mathrm{y}}_{\mathrm{nm}}(\mathrm{o}): \boldsymbol{E}_{\perp}(r,\theta) = \hat{y}\sqrt{2} f_\sigma J_n(X_\sigma \cdot r/a)\sin(n\theta) \quad (2)$$

$$\mathrm{LP}^{\mathrm{x}}_{\mathrm{nm}}(\mathrm{e}): \boldsymbol{E}_{\perp}(r,\theta) = \hat{x}\sqrt{2} f_\sigma J_n(X_\sigma \cdot r/a)\cos(n\theta) \quad (3)$$

$$\mathrm{LP}^{\mathrm{x}}_{\mathrm{nm}}(\mathrm{o}): \boldsymbol{E}_{\perp}(r,\theta) = \hat{x}\sqrt{2} f_\sigma J_n(X_\sigma \cdot r/a)\sin(n\theta), \quad (4)$$

where n, m are mode numbers and X_σ is the eigen value of the mode σ with (n, m). a expresses the radius of the waveguide and the normalization constant f_σ is

$$f_\sigma = \frac{Z_0}{a\sqrt{\pi} J_{n+1)}(X_\sigma)} = -\frac{Z_0}{a\sqrt{\pi} J_{n-1)}(X_\sigma)}. \quad (5)$$

Electric field profiles of typical lower order LP_{nm} modes are graphically plotted in Fig. 2. The direction of the electric field is oriented to Y-direction.

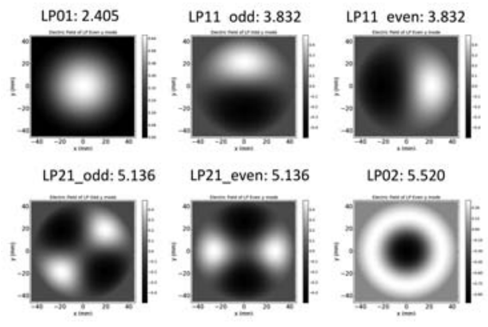

Fig. 2: Electric field profiles of $\mathrm{LP}_{01}, \mathrm{LP}_{11}(odd, even), \mathrm{LP}_{21}(odd, even), \mathrm{LP}_{02}$ -modes

Generally, a propagating mmw in a corrugated waveguide is expressed as a superposition of several eigen modes σ $(= 0 \cdots N)$. The electric field at the position of $(x_i, y_j.z_k)$ is described by the following equation;

$$\boldsymbol{e}_{tot}(x_i, y_j, z_k) = \sum_{\sigma=0}^{N} \sqrt{p_\sigma} \exp\{j(\phi_\sigma - k_\sigma z_k)\} \boldsymbol{E}_\sigma(x_i, y_j) \quad (6)$$

$$x_i = i \times \Delta x \quad (7)$$

$$y_j = j \times \Delta y \quad (8)$$

where $i, j = 0 \cdots M-1$ and p_σ, ϕ_σ and k_σ are the power, phase and wave-number of the propagating mode σ, respectively. The evaluation function W_{tot} for determining mode content is defined by the summation of square value of the difference between the measured O and theoretical T functions,

$$W_{tot}(p_\sigma, \phi_\sigma) = \sum_{k=0}^{n-1} W(z_k), \quad (9)$$

where

$$W(z_k) = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1} \{O(x_i, y_j, z_k) - T(x_i, y_j, z_k)\}^2 \quad (10)$$

$$T(x_i, y_j, z_k) = \frac{|\boldsymbol{e}_{tot}(x_i, y_j, z_k)|^2}{|\boldsymbol{e}_{tot}|^2_{MAX}} \quad (11)$$

When the mode with $\sigma = 0$ is assumed to be the LP_{01} fundamental mode with the phase $\phi_0 = 0$ and $\sum_{\sigma=0}^{N} p_\sigma = 1$, each p_σ, ϕ_σ can give the ratio of mode-content and the initial phase of each mode σ.

1) T. Shimozuma, et al. :, Plasma Conference 2011, Nov. 22-25, Kanazawa, Japan, 22P146-P.

2) K. Ohkubo, et al. :, Fus. Sci. and Tech. 62 (2012) 389.